The Journal of Arthroplasty 40 (2025) S27−S33

Contents lists available at ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

2024 ARCO Meeting

Which Radiographic View Visualizes the Initial Collapse in Osteonecrosis of the Femoral Head? A Computed Tomography Scan Study

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ARTICLE INFO

Article history:
Received 5 March 2025
Received in revised form
16 May 2025
Accepted 16 May 2025
Available online 23 May 2025

Keywords:
osteonecrosis of the femoral head
collapse
subchondral fracture
computed tomography
Dunn view

ABSTRACT

Background: An accurate diagnosis for staging osteonecrosis of the femoral head (ONFH), particularly in early-stage collapse, is essential for determining therapeutic strategies. Various radiographic views in different femoral positions have been used to detect femoral head collapse. However, previous studies have not established the optimal femoral position that can sensitively detect initial collapse on plain radiography. This study aimed to identify the most sensitive radiographic view for visualizing collapse in early-stage ONFH by analyzing reconstructed frontal images of the femoral head at multiple femoral positions on computed tomography (CT).
Methods: This study included 30 hips with early-stage ONFH (10 hips without collapse and 20 hips with collapse [< three mm] based on the anteroposterior and lateral radiographic images). The presence or absence of collapse in 10 reconstructed frontal images of the femoral head on CT scans, corresponding to 10 different femoral positions, was classified. Furthermore, the ability to detect collapse in each image was compared.
Results: The reconstructed frontal image of the femoral head on CT scans at 45° flexion and 20° abduction had the highest sensitivity for detecting collapse among the analyzed positions. Hence, it had a significantly greater sensitivity than the neutral position (86 versus 53%, $P < 0.01$). Of 70% who did not present with collapse on plain radiography had collapse on the reconstructed frontal image at 45° flexion and 20° abduction.
Conclusions: The plain radiographic image taken at 45° flexion and 20° abduction, referred to as the 45° Dunn view, had a greater diagnostic potential for early collapse in ONFH compared with the anteroposterior radiographic image. Nevertheless, further research should be performed to comprehensively investigate the areas where collapse occurs in ONFH and to identify the most effective femoral position for detecting collapse on plain radiography.

This study was supported by Health Labor Sciences Research Grant, the Ministry of Health Labor and Welfare, Japan (JPMH23FC1045).

Part of this work was presented at the 22nd International Meeting of Association Research Circulation Osseous 2024 in Osaka.

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to https://doi.org/10.1016/j.arth.2025.05.068.

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https://doi.org/10.1016/j.arth.2025.05.068
0883-5403/

Osteonecrosis of the femoral head (ONFH) causes acute hip pain in the early stages and leads to progressive collapse of the femoral head with joint destruction in the late stages. Joint-preserving procedures are conducted in the early stages. Meanwhile, total hip arthroplasty (THA) is performed for more advanced stages of ONFH, which is characterized by collapse or a fracture of the necrotic portion. The extent of collapse influences the clinical outcomes of various joint-preserving procedures [1]. Recent research has focused on early diagnosis and minimally invasive intervention combined with growth factors [1–5]. Therefore, accurate disease staging, particularly in the early stages, is essential to determine appropriate therapeutic strategies.

Plain radiography is still the cornerstone for the diagnostic evaluation of ONFH, and it underpins several well-known classification systems [6,7]. Most necrotic lesions are located in the superior-anterior area of the femoral head, where initial subchondral fractures often occur [8]. To effectively visualize collapse in this region, several lateral radiographic views in different femoral positions have been used.

However, the optimal femoral position with the highest sensitivity for visualizing initial collapse on plain radiography is yet to be determined. Therefore, it is important to assess which radiographic view allows for the early detection of femoral head collapse.

This study aimed to identify the most sensitive position for visualizing collapse in early-stage ONFH by using the reconstructed frontal plane of the femoral head on computed tomography (CT) scans at multiple femoral positions for radiographic views.

Materials and Methods

The ethics committee of our institution approved this study. All procedures involving human participants were performed in accordance with the ethical standards of the institutional research committee of our institution and the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Participants

The participants were identified using a prospectively maintained registry of hip arthroplasty at our institution from January 1, 2015 to January 1, 2024. All patients underwent preoperative CT scans as part of a protocol for hip arthroplasty planning. The plain radiographic and magnetic resonance images and medical records of the participants who underwent primary THA for ONFH were reviewed. A THA was indicated for patients experiencing unbearable and persistent pain. Patients who have late-stage ONFH classified as stage 3B (collapse $\geq$ three mm) and stage 4 (osteoarthritis) by the Japanese Investigation Committee (JIC) were excluded from the analysis [7,9]. In total, 30 hips from 28 patients who underwent primary THA for hip pain attributed to early-collapsed stage ONFH (eight and 20 hips from women and men, respectively; mean age 50 years) were reviewed. The cohort comprised 10 hips with pre-collapse stage ONFH classified as JIC stage 2 (demarcating sclerosis without collapse) and 20 hips classified as JIC stage 3A (collapse < three mm) based on the antero-posterior (AP) and lateral views of plain radiography. The lateral view of the femoral head was taken in the AP direction while the patient was in the supine position with the hip in 90° flexion and 45° abduction, according to the Sugioka method [10]. The location of the necrotic lesion was classified as type C1 in 15 hips and type C2 in 15 hips according to the JIC classification [7,9]. This classification is based on the central coronal section of the femoral head on T1-weighted images. Both type C1 and C2 lesions occupy more than the medial two-thirds of the weight-bearing portion. However, type C2 lesions extend laterally to the acetabular edge and type C1 lesions do not. The risk factors were corticosteroid-associated in 21 hips and alcohol-associated in nine hips.

In all participants, the CT scan images of the whole femur were acquired using a helical scanner with a slice thickness of 1.25 to 2.5 mm. The CT scan images of 30 femurs were evaluated. All images were reviewed, and the presence or absence of femoral head collapse was assessed by experienced orthopaedic surgeons. Collapse on CT scan was defined as step-off, flattening, or breach of the articular surface [11,12] (Figure 1).

Definition of the Analyzed Radiographic View at 10 Femoral Positions

To establish multiple femoral positions, a femoral coordinate system was defined. The posterior condylar plane [13,14] was defined using the most posterior point of the trochanteric region of the femur and the medial and lateral posterior condyles as the coronal plane [15]. The vertical axis was defined by projecting a line via the femoral head center and the knee center on the posterior condylar plane. The most distal end of the intercondylar notch was defined as the knee center (Figure 2).

This study assumed 10 radiographic views by reconstructing CT scan images as follows: To simulate the standard AP radiographic

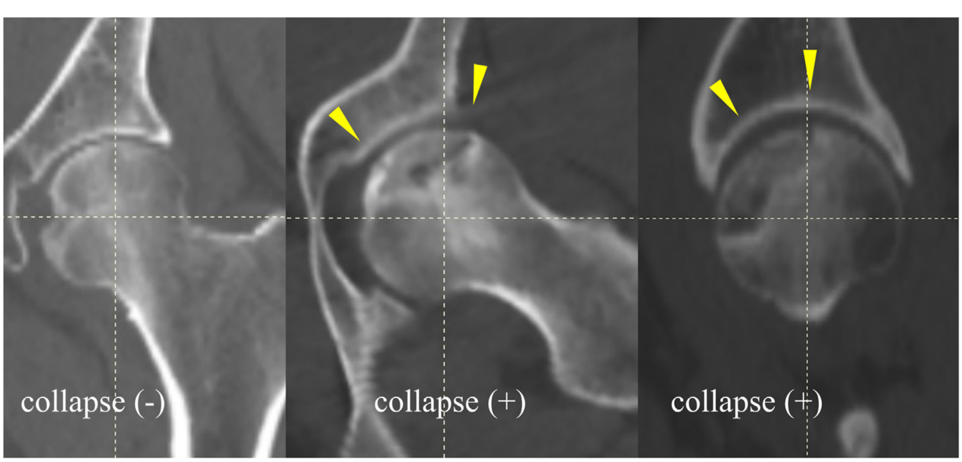

Figure 1. The presence of collapse, defined as step-off, flattening, and breaching of the articular surface, was determined in the reconstructed frontal plane, which included the femoral head center on the computed tomography scan image.

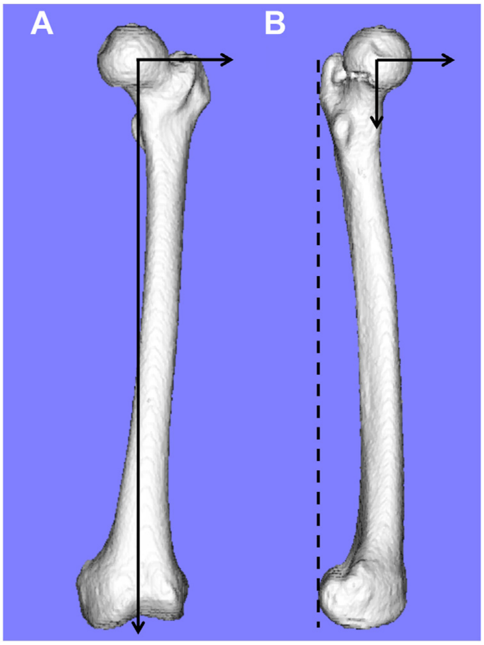

Figure 2. The neutral position of the femur was aligned using the femoral posterior condylar coordinate system, which was defined by the posterior condylar plane and the line passing through the femoral head center and the most distal end of the intercondylar notch. (A) Anteroposterior view. (B) Mediolateral view.

view acquired when the femur was in the neutral position, the frontal image including the femoral head center with zero position in the femoral coordinate system was examined, and the presence or absence of femoral head collapse was classified.

For the AP radiographic view acquired at 45° hip flexion, the craniocaudal axis on the sagittal image, including the femoral head center at the zero position, was rotated 45° in the extension direction. Consequently, the reconstructed frontal image was changed to represent the AP radiographic view at 45° hip flexion (Figure 3).

To simulate the AP radiographic view at 45° hip flexion combined with 20° hip abduction, the craniocaudal axis in the frontal image, including the femoral head center at the zero position, was initially rotated at a 20° angle in the adduction direction. Then, the cranio-caudal axis in the reconstructed sagittal image was rotated at a 45° angle in the extension direction. This reconstructed frontal image represented the AP radiographic view at 45° hip flexion combined with 20° hip abduction (Figure 3).

For the AP radiographic view at 30° hip external rotation, the mediolateral axis in the transverse image, including the femoral head center at the zero position, was initially rotated at a 30° angle in the internal rotation direction. As a result, the reconstructed frontal image changed to represent the AP radiographic view at 30° hip external rotation.

In total, 10 femoral positions were simulated: neutral position (neutral), 45° hip flexion (Flex45), 45° flexion combined with 20° abduction (Flex45/Abd20), 45° flexion combined with 45° abduction (Flex45/Abd45), 90° flexion (Flex90), 90° flexion combined with 20° abduction (Flex90/Abd20), 90° flexion combined with 45° abduction (Flex90/Abd45), 30° hip external rotation (ER30), 60° external rotation (ER60), and 90° external rotation (ER90) (Figures 3 through 5).

The presence or absence of femoral head collapse was classified in the 10 reconstructed frontal images, each representing the assumed radiographic views, including neutral, Flex45, Flex45/Abd20, Flex45/Abd45, Flex90, Flex90/Abd20, Flex90/Abd45, ER30, ER60, and ER90 [11,12] (Figure 1).

Data Analyses

The number of collapses observed in each view was tabulated, and the McNemar test was used to determine statistically significant differences in diagnostic performance between each view and

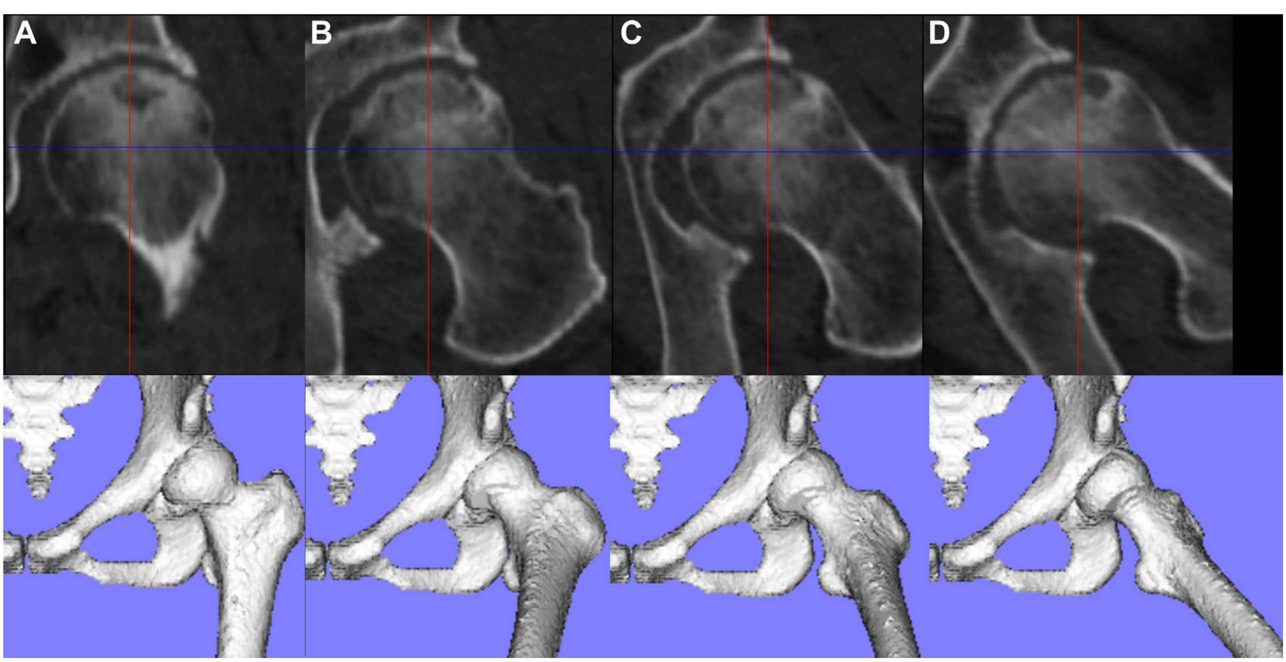

Figure 3. The analyzed reconstructed mid-frontal planes at following femoral positions: (A) the neutral position (neutral), (B) 45° hip flexion (Flex45), (C) 45° flexion combined with 20° abduction (Flex45/Abd20), and (D) 45° flexion combined with 45° abduction (Flex45/Abd45).

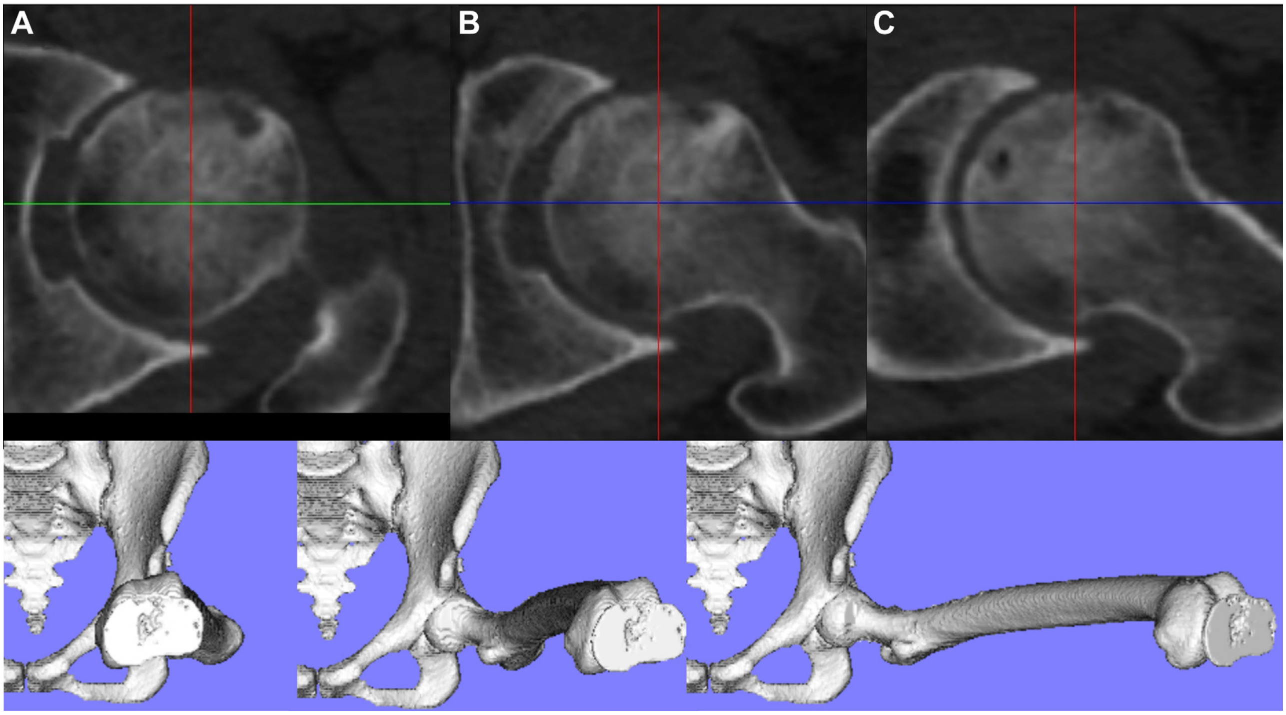

Figure 4. The analyzed reconstructed mid-frontal planes at the following femoral positions: (A) 90° flexion (Flex90), (B) 90° flexion combined with 20° abduction (Flex90/Abd20), and (C) 90° flexion combined with 45° abduction (Flex90/Abd45).

the neutral view ($P < 0.01$). We also analyzed the number of collapses observed in the neutral view combined with the Flex90/Abd45 view, which is usually evaluated in the clinical situation [7,9]. Subanalyses of stages 2 and 3A collapse were also conducted.

After classifying the presence or absence of collapse on the 10 views across 10 hips, the interobserver reproducibility for classification was evaluated by two independent orthopaedic surgeons (H.H. and R.H.) using Kappa coefficients. The intraobserver

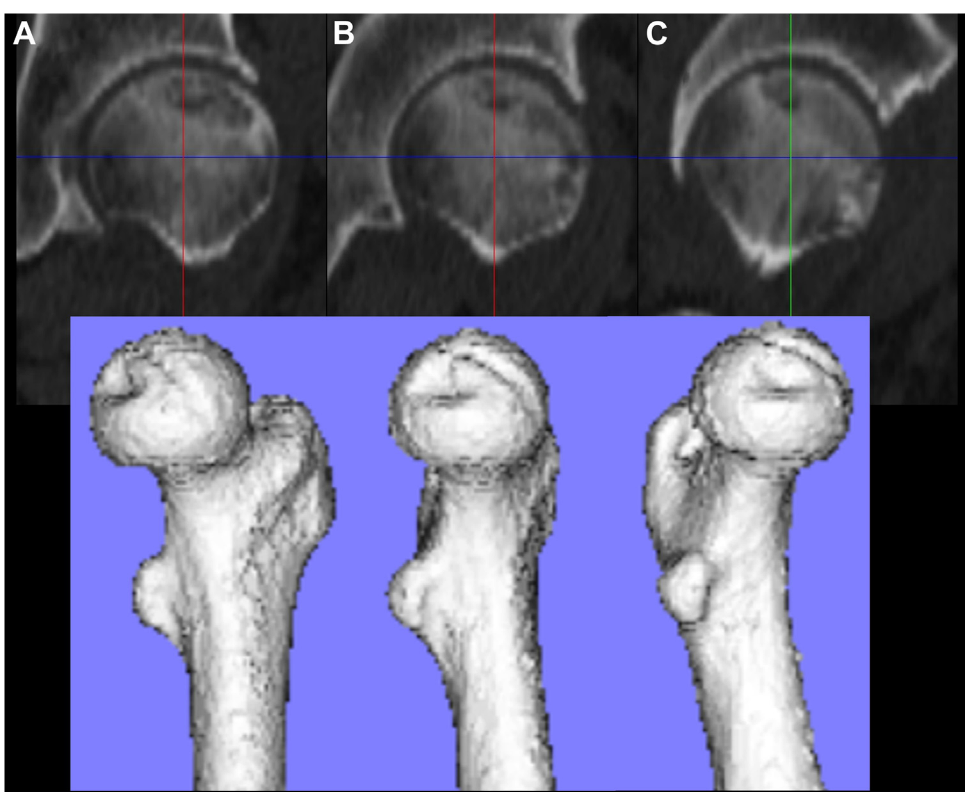

Figure 5. The analyzed reconstructed mid-frontal planes at the following femoral positions: (A) 30° hip external rotation (ER30), (B) 60° external rotation (ER60), and (C) 90° external rotation (ER90).

reproducibility for two measurements obtained by a single investigator (H.H.) was also assessed. The kappa value estimations for interobserver and intraobserver reproducibility were defined as follows: poor, ≤ 0.2; mild, 0.2 to 0.4; moderate, 0.4 to 0.6; good, 0.6 to 0.8; and excellent, 0.8 to 1 [16]. The kappa values for intraobserver and interobserver reproducibility were 0.861 and 0.781, respectively, which indicated good to excellent agreement. The Statistical Package for the Social Sciences software was used in the statistical analysis (IBM Inc., Tokyo, Japan).

Results

Femoral Position that can Sensitively Visualize Collapse in ONFH

Firgue 6 shows the incidence of visualizing collapse in each view. Collapse was observed in 16 hips (53%) at neutral, 26 hips (86%) at Flex45/Abd20, 22 hips (73%) at Flex45/Abd45, 17 hips (56%) at Flex90/Abd20, 16 hips (53%) at Flex90/Abd45, and 20 hips (67%) at neutral combined with Flex90/Abd45. Flex45/Abd20 had a significantly higher ability to detect collapse than neutral ($P < 0.01$).

Figure 7 shows the incidence of visualizing JIC stages 2 and 3A collapse. In the stage 2 analysis, 70% of the participants who did not present with collapse on plain radiographic images (JIC stage 2) had collapse at Flex45/Abd20 on CT scan. Meanwhile, 90% of the participants who did not present with collapse on plain radiographic images had collapse at the overall view on CT scan. In both stages, there was no significant difference in the ability to visualize collapse across all views compared with neutral.

Discussion

An accurate diagnosis for staging ONFH, particularly in early-stage collapse, is essential for determining appropriate therapeutic strategies. Plain radiography remains the mainstay for assessing the contour of the subchondral bone of the femoral head. Various radiographic views in different femoral positions have been used to detect femoral head collapse. However, previous studies have not established the optimal femoral position that sensitively visualizes collapse in early-stage ONFH on plain radiography. Our findings showed that the reconstructed frontal image of the femoral head on CT scan, assuming 45° flexion combined with 20° abduction, had the highest sensitivity for detecting collapse, which is significantly greater than the neutral position. Notably, 70% of participants who did not present with collapse on plain radiography (JIC stage 2) had collapse in the reconstructed frontal image at 45° flexion combined with 20° abduction.

Femoral Position that can Sensitively Visualize Collapse in ONFH on Plain Radiography

In clinical practice, several radiographic views of the proximal femur, including the AP view, lateral view according to the Sugioka method, and frog leg view, have been used to detect femoral head collapse [7,10,17,18]. However, to our knowledge, no study has compared femoral positions that can sensitively visualize initial collapse in ONFH on plain radiography. The present study examined 10 femoral positions, combining 0, 45, and 90° flexion; 0, 20, and 45° abduction; and 30, 60, and 90° external rotation. Among these positions, the reconstructed frontal image at 45° flexion combined with 20° abduction was the most effective for detecting collapse, and it significantly outperformed the neutral position. Thus, the plain radiographic image taken at 45° flexion combined with 20° abduction, commonly known as the 45° Dunn view, can have a sensitive diagnostic potential for early ONFH collapse compared with the standard AP view.

Most necrotic zones are found in the superior-anterior segment of the femoral head, where collapse typically occurs first. Previous micro-CT scan studies have shown that initial subchondral fractures were more likely to appear in the superior-anterior 30 and 45° planes during the early collapse stage [8]. Therefore, observing the femoral head contour in the superior-anterior 45° area is effective for detecting early-stage collapse in ONFH [17]. This could be the reason why the views at 90° flexion combined with abduction showed limited visualization of collapse. The frog-leg view, taken at 45° flexion combined with abduction and external rotation, is another common radiographic method for identifying collapse in ONFH. Meyer et al. compared six radiographic views. Results showed that the Dunn 45° view had the best femoral head asphericity. Meanwhile, the AP view was more likely to miss it [19]. Similarly, Uemura et al. found that the contour of the superior-anterior area at approximately 45° of the femoral head was better visualized in the 45° Dunn view [20]. Other studies have also

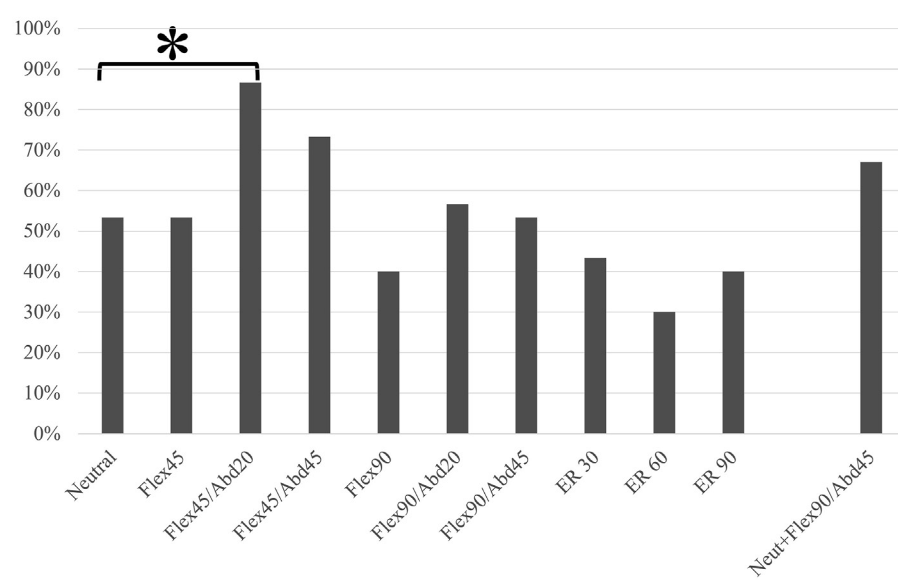

Figure 6. The incidence of visualizing collapse in each view is shown. The ability to detect collapse at 45° flexion combined with 20° abduction was significantly higher than that at neutral view (*$P < 0.01$). Flex, flexion; Abd, abduction; ER, external rotation.

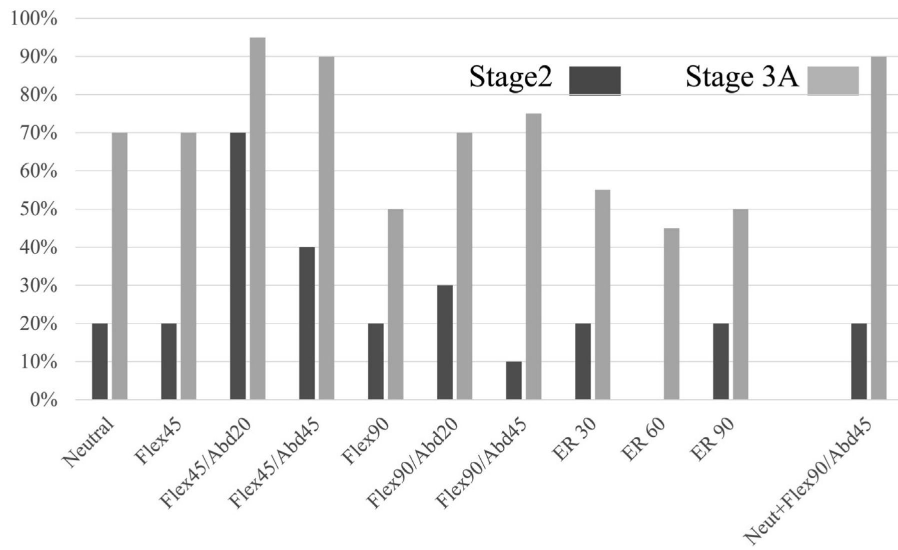

Figure 7. The incidence of visualizing Japanese Investigation Committee stages 2 and 3A collapse in each view. In the stage 2 analysis, 70% of the participants who had precollapse on plain radiography had collapse at 45° flexion combined with 20° abduction view. In both stages, there was no significant difference in the ability to visualize collapse between all views and the neutral view. Flex, flexion; Abd, abduction; ER, external rotation.

revealed that the Dunn view is optimal for visualizing the superior-anterior region of the femoral neck, which is often altered by the cam morphology [21,22]. To diagnose painful hip conditions such as ONFH and femoro-acetabular impingement, a plain radiographic view in the 45° flexion and abduction position may be reasonable in addition to the AP view [23].

Effective Methods for Detecting Early Collapse in ONFH on CT Scan Images

Despite its limitations in versatility and radiation exposure, CT scans excel in detecting small lesions, including early ONFH collapse [24]. It is a sensitive method for identifying subchondral fractures of the femoral head and for providing a clear outline of the subchondral bone [11,24–26]. Previous studies have shown that CT scans, like magnetic resonance imaging, are essential for more accurate disease staging [12,27,28]. Notably, approximately 20% of the hips with stages I or II ONFH based on the Association Research Circulation Osseous classification on plain radiography had stage III ONFH on CT scan [28]. The CT scan is more effective in detecting subchondral fractures in ONFH than plain radiography. Our study showed that 70% of the participants who did not present with collapse on plain radiography exhibited collapse at 45° flexion combined with 20° abduction on CT scan. Furthermore, 90% of the hips presented with collapse across all 10 views. Specific reconstructed images focusing on the anterior-superior area of the femoral head had superior sensitivity for detecting early collapse compared with frontal plane images. Thus, observing the anterior-superior cross-sectional image of the femoral head on a CT scan can be an efficient approach for detecting early ONFH collapse.

Potential Limitations

This study had several potential limitations. Actual plain radiographic images in various femoral positions were not evaluated. In clinical settings, variations in patient positioning during radiograph acquisition cannot be avoided. The current CT scan simulation study allowed for an accurate and reproducible assessment of multiple femoral positions. Nevertheless, further research should evaluate actual radiographic results. Also, the limited number of participants and the analysis of femoral positions might have restricted the findings. Furthermore, in addition to the 10 positions analyzed, other femoral positions could be more sensitive in detecting ONFH collapse. Therefore, further studies should be performed to comprehensively investigate areas where ONFH collapse is likely to occur and to identify the most effective femoral positions for plain radiography.

Conclusions

This study aimed to provide guidance on selecting the most effective radiographic view for detecting femoral head collapse in ONFH. Results showed that the femoral position at 45° flexion and 20° abduction can facilitate a more sensitive visualization of collapse compared with the neutral position. Therefore, plain radiography with the 45° Dunn view has a significant diagnostic potential for identifying ONFH collapse compared with standard AP radiography. Nevertheless, further research should be performed to comprehensively investigate areas where ONFH collapse is likely to occur and to identify the most effective femoral position for detecting this condition on plain radiography.

CRediT authorship contribution statement

Hidetoshi Hamada: Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Kazuma Takashima:** Writing – review & editing, Validation, Data curation. **Ryo Higuchi:** Validation, Methodology, Data curation. **Wataru Ando:** Writing – review & editing, Data curation. **Nobuhiko Sugano:** Writing – review & editing, Supervision. **Keisuke Uemura:** Writing – review & editing, Supervision, Methodology, Data curation.

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